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Numerical Simulation of Fracture Failure and Propagation due to Fluid Injection in the Context of Embedded Discrete Fractures

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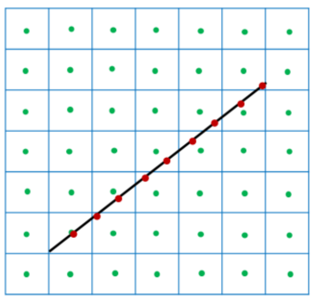
1 Introduction

This work focuses on developing a numerical framework to study the physics of induced seismicity due to fluid injection into a fractured domain. As a consequence of shear or tensile failure due to fluid injection, new fractures are created adjacent to the tips of the preexisting ones due to tensile or mixed mode failure. Continuing the fluid injection, these new fractures then propagate and may coalesce with the other fractures or form again new fractures.

2 Method overview

Numerical simulation of such systems require complete modeling of the coupled solid and fluid mechanics including shear and tensile failure. We employ an embedded discrete fracture representation, where large fractures are described by discrete manifolds in an elastic damaged matrix domain. To properly account for the displacement discontinuities due to irreversible failure of fractures, we developed an extended finite volume method (XFVM) and use it in this study. The following figure provides illustration:



$$\nabla.\tilde{\sigma} + \vec{f} = 0$$

$$\tilde{\sigma} = \lambda(\nabla.\vec{u})\,\tilde{I} + G(\nabla\vec{u} + \nabla\vec{u}^{T})$$

$$\vec{u} \approx \sum_{I=1}^{N_e} \vec{u}_I N_I(x) + \sum_{j=1}^{N_s} \left(s_n^J N^J(x) + s_t^J N^J(x)\right)$$

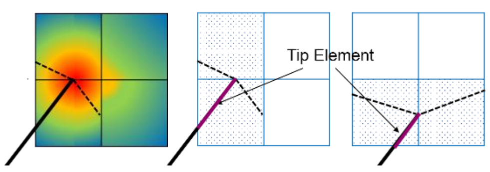
$$N^J(x) = \sum_{p=1}^{N_e} N_p^J(x)\, H_p^J(f^J(x))$$

$N_I(x)$ and $N^J(x)$ are bilinear and Heaviside basis functions, s_t^J is the tangential and s_n^J is the normal degree of freedom of the fracture segment. At each iteration the shear and tensile failure criteria are checked and in case of failure, force constraint equations are added to the system of equations.

For initiation of new fractures or for fracture propagation, different propagation criteria such as the minimum principle stress criterion and the stress intensity factor at the crack tips are integrated.
For the minimum principle stress criterion the stress distribution at the fracture tip is needed which is calculated using two step weight averaging:

$$\sigma_{ave} = \left(\sum_{i=1}^{n} w_i\right)^{-1} \sum_{i=1}^{n} w_i \sigma_i\,, \quad \sigma_{min} = \left(\sum_{i=1}^{n} w_i\right)^{-1} \sum_{i=1}^{n} w_i \sigma_i \ ;\ \exists\, i : \sigma_i \le \sigma_{ave}$$

$$w(r) = \left(\sqrt{2\pi}\, l\right)^{-1} \exp\left(-r^2/_{4\, l^2}\right)$$



For calculating the stress intensity factors the method proposed by Yan is used:

$$K_{eq} = \frac{1}{2}\cos\left(\frac{\theta}{2}\right)\left[K_I(1+\cos\theta) - 3K_{II}\sin\theta\right]$$

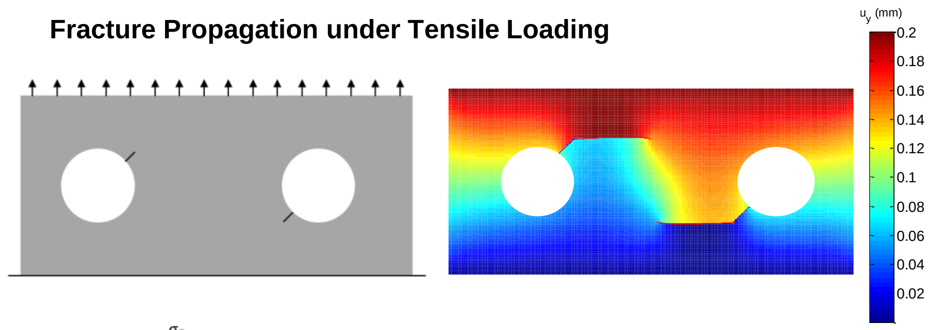
$$K_I = \frac{E}{8(1-\nu^2)}\sqrt{\frac{2\pi}{L}}\, S_n$$

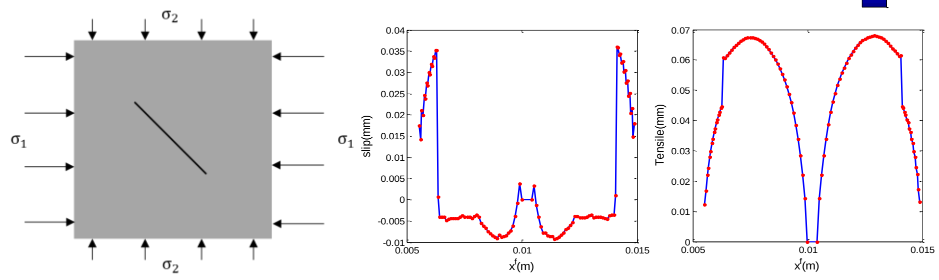
$$K_{II} = \frac{E}{8(1-\nu^2)}\sqrt{\frac{2\pi}{L}}\, S_t$$

$$\theta = \begin{cases} 0 & K_{II} = 0 \\ 2\arctan\left(\frac{1}{4}\left(\frac{K_I}{K_{II}} - sgn(K_{II})\sqrt{8 + \left(\frac{K_I}{K_{II}}\right)^2}\right)\right) & K_{II} \neq 0 \end{cases}$$

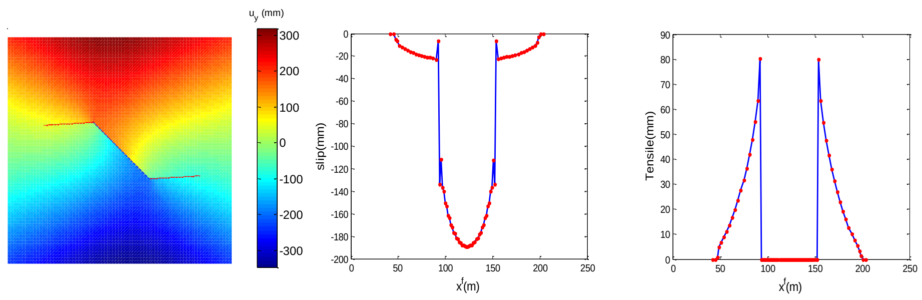
4 Results and discussion

Fracture Propagation under Tensile Loading

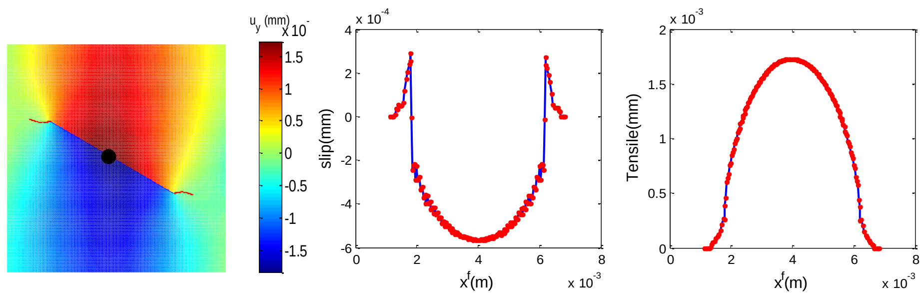




Wing Fracture Propagation under Asymmetric Compression



Fracture Propagation due to Fluid Injection
Fluid flow is computed within both the damaged matrix and the fractures, while mass exchange is accounted for by modeled transfer rates.



5 Conclusion

A XFVM method in HFR framework is employed here to study fracture failure and propagation due to different types of loadings and fluid injection. Two fracture propagation models are integrated into this method, such as minimum principle stress and stress intensity factor criteria.

6 References

1. Deb, Rajdeep, and Patrick Jenny. Finite volume–based modeling of flow-induced shear failure along fracture manifolds (2017).
2. Yan, Xiangqiao. A special crack tip displacement discontinuity element (2004).
3. Kamali, Amirhossein, and Ahmad Ghassemi. Analysis of injection-induced shear slip and fracture propagation in geothermal reservoir stimulation (2018).